

The Interacting Early-Type Binary V382 Cyg

B. Yaşarsoy¹ and K. Yakut^{1,2}

¹*Department of Astronomy and Space Sciences, University of Ege, 35100, Bornova-İzmir, Turkey*

²*Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA*

ABSTRACT

We present photometric and spectroscopic data analysis and orbital period study of an early-type interacting binary system V382 Cyg by using all the available data. We made a simultaneous light and radial velocity curve solution. The derived physical parameters of the primary and secondary stellar components are $M_1 = 27.9(5) M_\odot$, $M_2 = 20.8(4) M_\odot$, $R_1 = 9.7(2) R_\odot$, $R_2 = 8.5(2) R_\odot$, $\log(L_1/L_\odot) = 5.152(20)$ and $\log(L_2/L_\odot) = 4.954(19)$ while the separation of the components is $a = 23.4 R_\odot$. Newly obtained parameters yield the distance of the system as 1466(76) pc. Analyses of the mid-eclipse times indicate a period increase of $\frac{dP}{dt} = 4.2(1) \times 10^{-7}$ days/yr that can be interpreted in terms of the high mass transfer ($\frac{dM}{dt} = 6.1(5) \times 10^{-6} M_\odot/\text{yr}$) from the less massive component to the more massive component. Finally we modelled the evolution of the components using nonconservative codes and discussed the obtained results. The age of the binary system is estimated as 3.85 Myr.

Subject headings: Stars: binaries - stars: binaries: close - stars: individual: V382 Cyg - stars: fundamental parameters - stars: early-type - stars: evolution

1. Introduction

Massive interacting binary systems are the progenitor candidates of some high energy phenomena in astrophysics (e.g., supernovae). Solar-type close binary systems with convective envelopes can evolve in different ways than close massive stars. Yakut & Eggleton (2005) modelled late-type close binary systems assuming conservative and non-conservative cases. The authors proposed that a detached configuration can evolve into a semi-detached configuration followed by a contact configuration. Except late-type systems, we have less information on the evolution of the interactive massive binary systems, since there are a few binary systems with well-determined parameters. Therefore, systems like V382 Cyg, RY Sct (Djurasevic et al. 2008) and V729 Cyg (Yasarsoy et al. 2013, submitted), etc. are crucial in observational studies of close massive binaries.

Photometric studies of V382 Cyg have been published by different researchers. The binary system V382 Cyg was discovered as a variable star by Morgenthau (1935) and Petrov (1946) and

they classified the system as an eclipsing binary. The photometric UBV light variations of the system was obtained by Landolt (1964) by using 16-inch KPNO telescope. Modelling the light and radial velocity curves of the system, Bloomer et al. (1979) derived an orbital inclination of 87° and $M_1 = 26.7 (5) M_\odot$ and $M_2 = 18.9 (4) M_\odot$. Later photometric studies were performed by Cester et al. (1978), Mayer et al. (1986), Harries et al. (1997), Değirmenci et al. (1999) and Qian et al. (2007).

Spectroscopic studies of the system were provided by Pearce (1952), Popper (1978), Koch et al. (1979), Harries et al. (1997), Burkholder et al. (1997) and Mayer et al. (2002). Popper (1978) studying the He I and He II lines derived the semi-amplitude of the radial velocity curve and the mass function for the components as $K_1 = 255 \text{ km s}^{-1}$, $K_2 = 360 \text{ km s}^{-1}$, $M_1 \sin^3 i = 26.7 M_\odot$ and $M_2 \sin^3 i = 18.9 M_\odot$. Later on Popper and Hill (1991) recalculated the parameters as $K_1 = 276 \text{ km s}^{-1}$ and $K_2 = 400 \text{ km s}^{-1}$ and the masses as $M_1 = 32.6 (1.8) M_\odot$ and $M_2 = 22.9(1.3) M_\odot$. By using photometric and spectroscopic data Harries

et al. (1997) derived the mass of the components as $M_1 = 26.0 (7)M_\odot$ and $M_2 = 19.3 (4)M_\odot$. Recently, Mayer et al. (2002) derived the masses for the stars as $M_1 = 29.2 M_\odot$ and $M_2 = 21.2 M_\odot$. Spectral types of the components were defined by Pearce (1952) as O6.5+O7.5, by Popper (1980) as O7.3+O7.7, by Harries et al. (1997) as O7.3+O7.7 and by Burkholder et al. (1997) as O6.5V(f) + O6V(f). They gave distance module for the system as 11.5(5) mag. Garmany & Stencel (1992) classified V382 Cyg as a member of Cyg OB1 association.

2. New Observations

The observations were carried out on 25 nights in 2007-2011 with the 40-cm telescope that is equipped with the 2048×2048 Alta CCD camera at Ege University Observatory (EUO). The exposure times are 15 s for B, 5 s for V, 4 s for R and 4 s for I filter. The reduction and analysis of the frames have been managed using the IRAF packages to subtract the bias and dark then divide flat field, followed by aperture photometry (DIGIPHOT/APPHOT). Comparison and check stars are selected as HD 193204 ($V=8^m32$, $B-V=0^m46$), GSC 2684 1450 ($V=9^m60$, $B-V=1^m12$), HD 228802 ($V=9^m63$, $B-V=0^m44$) and HD 193344 ($V=7^m60$, $B-V=-0^m06$). The magnitudes and colors are obtained from TYCHO-2 catalogue (Høg et al. 2000). We have studied all the nights and each frames separately during the data reduction and standard deviations are estimated for B, V, R and I bands as 0.018, 0.013, 0.016 and 0.015, respectively. 3095, 2861, 2871 and 2772 points are obtained in *B*, *V*, *R* and *I* bands, respectively. We list all the observed data in Table 1. The light curves of the system obtained in this study are shown in Fig. 1a.

We obtained three new minima times throughout these new observations. They are collated with those published and listed in Table 2 with their errors. Using Table 2 we derived a new linear ephemeris Eq. (1) that we believe to be useful for future studies on the system:

$$\text{HJD MinI} = 24\,54344.4972(8) + 1.8855270(2) \times E. \quad (1)$$

Table 1: Observational points of V382 Cyg. Heliocentric Julian Date, phase, (Δm) and their corresponding filters are listed. (Δm) is the magnitude difference between variable (V382 Cyg) and comparison star (HD 193204). The phases were calculated using the Eq. (1). Table 1 is given in its entirety in the electronic edition of this paper. A portion of it is shown here for guidance regarding its form and content.

HJD	Phase	Δm	Filter
2454292.33107	0.3334	0.331	B
2454292.33444	0.3352	0.330	B
2454292.33540	0.3357	0.324	B
2454292.33636	0.3362	0.326	B
2454292.33731	0.3367	0.325	B
2454292.33826	0.3372	0.328	B
2454292.33922	0.3377	0.315	B
2454292.34018	0.3382	0.326	B
2454292.34113	0.3387	0.332	B
2454292.34209	0.3392	0.337	B
2454292.34304	0.3397	0.330	B
2454292.34400	0.3403	0.331	B
2454292.34495	0.3408	0.338	B
2454292.34592	0.3413	0.329	B
2454292.34688	0.3418	0.327	B

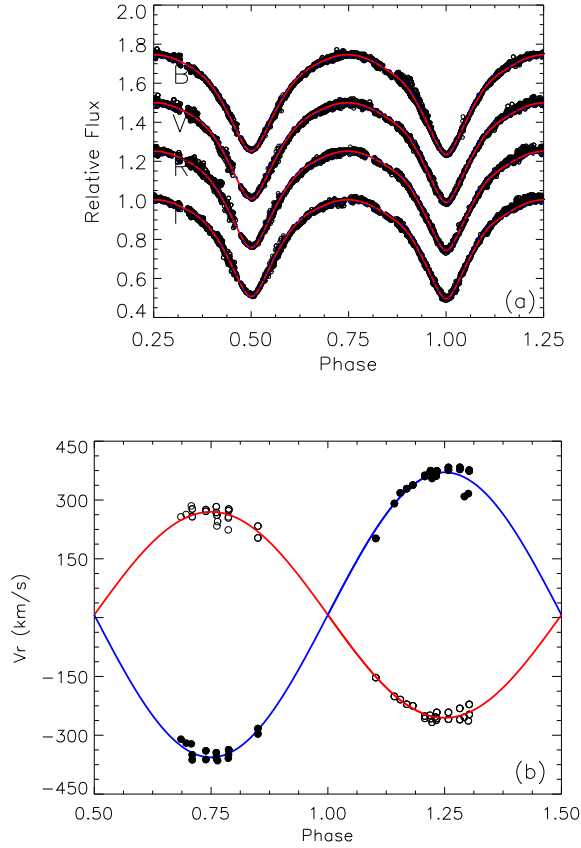


Fig. 1.— (a) The observed and the computed light and (b) radial velocity curves of V382 Cyg. The light curves in B, V, and R bands are altered by values of 0.75, 0.50, and 0.25, respectively, for a good visibility. See text for details.

3. Eclipse timings and period study

The difference between the observed (O) and calculated (C) times of minima in an eclipsing binary system can provide us information about any orbital period variation. The orbital period study of V382 Cyg was provided by Mayer et al. (1986), Mayer et al. (1998), Değirmenci et al. (1999) and Qian et al. (2007). Using times of minima Mayer et al. (1986) deduced the linear elements of the system. Değirmenci et al. (1999) taking into account only the mass transfer between the components derived the mass transfer rate from the less massive component to the more massive one as $5.0 \times 10^{-6} \text{ M}_{\odot} \text{ yr}^{-1}$. Qian et al. (2007) analyzed the O-C diagram assuming both mass transfer ($\dot{M} = 4.3 \times 10^{-7} \text{ M}_{\odot} \text{ yr}^{-1}$) and a third body.

Unlike previous studies of V382 Cyg, in this study we used only the most accurate (photoelectric and CCD data) minima times. We solve the O-C curve to find a parabolic variation which can be ascribed as mass transfer from the less massive companion to the more massive one. A total of 65 data points obtained with photometric/CCD observations are used to study the period variation of the system. Table 2 shows the data used during the analysis. The weighted least-squares method is used in order to determine the parameters of the upward parabolic variation. The residuals $(O-C)_I$ indicate a quadratic solution (Fig. 2a). In order to estimate the light elements, the differential correction method is used. The residuals $(O-C)_{II}$ show a sinusoidal variation (Fig. 2b). Therefore, we assumed a sinusoidal variation superposed on an upward parabola during O-C analysis. A sine-like variation in the O-C curve, where both the primary and the secondary minima follow the same trend, suggests the light time effect via the presence of a tertiary component. We used Eq. (2) during the O-C analysis.

$$\begin{aligned} \text{MinI} = & T_o + P_o E + \frac{1}{2} \frac{dP}{dE} E^2 \\ & + \frac{a_{12} \sin i'}{c} \left[\frac{1-e'^2}{1+e' \cos v'} \sin(v' + \omega') + e' \sin \omega' \right] \end{aligned} \quad (2)$$

where T_o is the starting epoch for the primary minimum, E is the integer eclipse cycle number, P_o is the orbital period of the eclipsing binary and a_{12} , i' , e' and ω' are the semi-major axis, inclination,

eccentricity and the longitude of the periastron of eclipsing pair about the third body and v' denotes the true anomaly of the position of the center of mass. Time of periastron passage T' and orbital period P' are the unknown parameters in Eq.(2) (see Kalomeni et al. 2007 for details).

4. Simultaneous solutions of light and radial velocity curves

The BVRI light curves obtained in this study are solved simultaneously with the radial velocity curve of Harries et al. (1997) and Mayer et al. (2002) using PHOEBE (Prša & Zwitter 2005) which is based on the WD code (Wilson & Devinney 1971; Wilson 1979; Wilson 1990). During the solution we used weighted light curves that are constructed according to the standard deviation of each filter. The effective temperature of the hot star is chosen according to spectroscopic studies. The albedos values A_1 and A_2 , for the hot and cooler components are adopted from Rucinski (1969), whilst the values of the gravity darkening coefficients g_1 and g_2 are taken from von Zeipel (1924). The logarithmic limb-darkening law is used with the coefficients adopted from van Hamme (1993) for a solar composition star. The adjustable photometric parameters are orbital inclination, i , surface potential, $\Omega_{1,2}$, temperature of the secondary component T_2 , luminosity L_1 and the mass ratio q . The center of mass velocity V_0 and semi-major axis a are also set as free parameters as well as the time of minimum light, T_0 and the orbital period, P . Table 4 summarizes the result of the analysis. B , V , R and I light curves and the velocity curve computed using the determined parameters are shown by solid lines in Fig. 1a.

During solution we assumed both contact (C) and semi-detached (SD) configurations. We emphasized that both solutions have similar results (see Table 4). In Fig. 1 the light curve fits for a contact and a semi-detached configurations are shown with a dotted and a solid line, respectively. For the contact model the filling factor, which is expressed by $(\Omega_{\text{in}} - \Omega)/(\Omega_{\text{in}} - \Omega_{\text{out}})$ that varies from zero to unity from the inner (Ω_{in}) to the outer critical surface (Ω_{out}), is calculated to be $f = 0.09$. New solutions indicate that the system has a weak contact degree or that it is a semi-detached binary with a near-contact configuration.

Table 2: Times of minimum light for V382 Cyg.

HJD* Min	Ref	HJD Min	Ref	HJD Min	Ref
2436814.7725	1	2448167.4765	7	2449913.4766	17
2438987.8298	1	2448186.3306	7	2449913.4785	10
2440385.9310	1	2448186.3316	7	2449915.3654	17
2440386.8761	1	2448447.4743	8	2449929.5074	17
2440387.8173	1	2448447.4764	8	2449930.4476	17
2441129.7698	1	2448498.3835	8	2449931.3909	17
2442651.3844	2	2448498.3844	8	2449945.5342	17
2442659.8678	3	2448564.3740	9	2449946.4757	17
2442940.8071	4	2448839.6629	10	2449947.4157	18
2442961.5424	3	2448843.4381	11	2449947.4171	17
2443366.9333	5	2448843.4395	12	2450671.4673	19
2444445.4450	6	2448843.4397	12	2451413.4316	20
2444757.4930	6	2448859.4664	11	2451429.4568	20
2444842.3538	6	2448878.3252	10	2452817.2130	21
2445598.4426	5	2449221.4844	13	2453837.2977	22
2446274.3971	5	2449221.4857	13	2455430.5686	23
2446325.3087	5	2449518.4527	14	2455483.361	24
2446668.4782	5	2449534.4780	15	2455811.4399	25
2447030.4922	3	2449550.5029	14	2454344.4913(4)	26
2447099.3141	3	2449567.4771	16	2455003.4938(5)	26
2447444.3744	3	2449568.4222	16	2455897.2295(3)	26
2448167.4747	7	2449880.4846	17		

References for Table 2. 1- Landolt(1975) 2- Mayer(1980) 3- Mayer et al.(1991) 4- Bloomer, Burke, & Millis (1979) 5- Mayer et al.(1986) 6- Andrakakou et al.(1980) 7- Hübscher, Agerer, & Wunder(1991) 8- Hübscher, Agerer, & Wunder(1992) 9- Blättler(1992) 10- Mayer et al.(1998) 11- Peter(1992) 12- Hübscher, Agerer, & Wunder(1993) 13- Hübscher, Agerer, & Wunder(1994) 14- Peter (1994) 15- Agerer & Hübscher(1995) 16- Blaettler(1994) 17- Degirmenci et al.(1999) 18- Agerer & Hübscher(1996) 19- Agerer & Hübscher(1998) 20- Agerer & Hübscher(2001) 21- Nagai(2004) 22- Qian et al.(2007) 23- Hübscher(2011) 24- Paschke(2010) 25- Zasche et al.(2011) 26- present study.

Table 4: Simultaneous analyses results of the light and radial velocity curve and their formal 1σ errors for V382 Cyg. The column headers C and SD refer to the contact model and semi-detached model, respectively. See text for details.

Parameter	C	SD
i ($^\circ$)	84.5(1)	85.3(2)
$q = M_h/M_c$	0.7439(14)	0.745(2)
a (R_\odot)	23.45(13)	23.47(12)
V_0 (kms^{-1})	7.1(1.6)	6.3(1.6)
Ω_1	3.275(3)	3.390(9)
Ω_2	3.275(3)	3.320
T_1 (K)	36000	36000
T_2 (K)	34415(270)	34578(240)
Fractional radius of primary comp.	0.4139(5)	0.4087(2)
Fractional radius of secondary comp.	0.3604(6)	0.3526(2)
$A_1 = A_2$	1.0	1.0
$g_1 = g_2$	1.0	1.0
Luminosity ratio: $\frac{L_1}{L_1+L_2}$ (%)		
B	57.9	56.2
V	58.0	56.3
R	57.7	56.1
I	57.5	55.8

Table 3: Orbital elements of the tertiary component and mass transfer ratio for V382 Cyg. The standard errors 1σ , in the last digit are given in parentheses.

Parameter	Unit	Value
T_o	[HJD]	2436814.7599(59)
P_o	[day]	1.885515(2)
P'	[year]	43.9(1.7)
T'	[HJD]	2419843(1611)
e'		0.41(8)
ω'	[$^\circ$]	34(15)
$a_{12} \sin i'$	[AU]	2.49(14)
$f(m)$	[M_\odot]	0.0080(2)
$m_{3;i'=30^\circ}$	[M_\odot]	5.7
$m_{3;i'=90^\circ}$	[M_\odot]	2.8
$\frac{1}{2} \frac{dP}{dE}$	[c/d]	$1.08(1) \times 10^{-9}$

5. Results and Conclusion

Newly obtained B, V, R and I light curves of the early-type interacting system V382 Cyg have been solved with earlier published spectroscopic studies. We derived the orbital and the physical parameters of the components from simultaneous solution and listed the physical parameters in Table 5. We calculated the masses as $27.9 M_\odot$ and $20.8 M_\odot$ which are $\sim 7\%$ higher than those given by Harries et al. (1997) and $\sim 7\%$ lower than Mayer et al. (2002) results. The distance of the system to the Sun is estimated as 1455 ± 76 pc using the observed parameters. During the calculations bolometric corrections are taken from Lanz & Hubeny (2003), the effective temperature and absolute magnitude of the Sun are taken as 5777 K and 4.732 mag. Garmany & Stencel (1992) proposed that V382 Cyg may be a member of the Cyg OB1 association. The distance to Cyg OB1 reported by Uyaniker et al. (2001) in the range from 1.25 kpc to 1.83 kpc. In this study, the distance of V382 Cyg was found to be within this range, so it is likely to be a member of Cyg OB1.

We have collected 65 times of mid-eclipses including our three new ones to search any periodic variation. Analysis of O–C residuals can give us the reason of a periodic and/or non-periodic variation. We applied the least-square method to the Eq. (2) to find the period change rate. Then the mass transfer rate is calculated and the possible third body parameters are estimated (Table 3). According our analysis, there is a mass transfer from the less massive (ini-

tially massive one) to the more massive component ($\frac{dM}{dt} = 6.1 \times 10^{-6} M_\odot/\text{yr}$) and the period change rate ($\frac{P}{P} = 4.5 \times 10^6$). In this study, the obtained mass transfer ratio is nearly ten times higher than that of Qian et al. (2007). This difference is probably due to their formalism. Additionally, we found new parameters for the tertiary component with 43.9 yrs outer period.

Isolated massive stars and massive stars in binary systems (e.g. V382 Cyg) evolve in different ways. The evolutionary path towards the final supernovae will become significantly different. The nature of the final stellar remnant may also be altered so that while a neutron star might be expected, mass transfer may lead to a black hole formation. Observations of systems similar to V382 Cyg can allow us to reveal the nature of the binary evolution and may help us to understand the possible variation of stellar lifecycles (see Eggleton 2010, Eldridge & Stanway 2009 and Yakut et al. 2013). Using our newly obtained physical parameters we provide an evolution model of the massive interacting binary system V382 Cyg. We used the TWIN version of the EV code (Yakut & Eggleton 2005, Eggleton 2008, Eggleton 2010) that has been developed by Peter P. Eggleton.

We run a few models using different initial parameters. Among these models the best agreement with the observations is obtained for the model binary system whose initial period is 1.72 days, with a primary and secondary masses $28 M_\odot$ and $23.5 M_\odot$. The first 28 models shrink slightly since the ZAMS is somewhat artificial. The massive compo-

Table 5: Astrophysical parameters of the system. The standard errors 1σ in the last digit are given in parentheses.

Parameter	Unit	Primary	Secondary
Mass (M)	M_{\odot}	27.9(5)	20.8(4)
Radius (R)	R_{\odot}	9.7(2)	8.5(2)
Temperature (T_{eff})	K	36000	34415(270)
Luminosity (L)	$\log(L_*/L_{\odot})$	5.152(20)	4.954(19)
Surface gravity ($\log g$)	cms^{-2}	3.91	3.90
Bolometric magnitude (M_b)	mag	-8.15	-7.65
Absolute magnitude (M_V)	mag	-4.75	-4.38
Period change rate (\dot{P})	d/yr	$4.2(3) \times 10^{-7}$	
Mass transfer ratio (\dot{M})	M_{\odot}/yr	$6.1(4) \times 10^{-6}$	
Distance (d)	pc	1466(76)	

ment fills its Roche lobe and RLOF begins at model 123. At model 201 the parameters are very consistent with the current observed parameters (Table 6). After two more models it reaches a contact phase. This configuration is consistent with the O-C analysis (*see* §3). Therefore, our models show that the system looks like a semi-detached system but very close to a contact phase. We plotted our result in the H-R diagram and Mass-Radius planes (Fig. 3). We found the age of the system to be 3.85 Myr which is in the range of age of Cygnus OB1 (e.g., Massey et al. 1995).

Acknowledgments

The authors would like to thank Peter P. Eggleton for his valuable comments and suggestions to improve the quality of the paper and for providing the current version of the EV(TWIN) code and, B. Kalomeni for helpful comments. We are very grateful to an anonymous referee for his/her comments and helpful constructive suggestions which helped us to improve the paper. This study was supported by the Turkish Scientific and Research Council (TÜBİTAK 111T270) and the Ege University Research Fund. KY acknowledges support by the The Turkish Academy of Sciences (TÜBA). The current study is a part of PhD thesis of B. Yaşarsoy.

REFERENCES

Agerer, F. & Hübscher, J. 1995, IBVS, 4222, 1
Agerer, F. & Hübscher, J. 1996, IBVS, 4383, 1

Agerer, F. & Hübscher, J. 1998, IBVS, 4606, 1
Agerer, F. & Hübscher, J. 2001, IBVS, 5016, 1
Andrakakou, M., et al. 1980, BBSAG, 49, 1
Blaettler, V. 1994, BBSAG, 107, 1
Blättler, E. 1992, BBSAG, 99, 1
Bloomer, R. H., Burke, E. W. & Millis, R. L. 1979, BAAS, 11, 439
Burkholder, V., Massey, P. & Morrell, N. 1997, ApJ, 490, 328
Cester, B., Fedel, B., Giuricin, G., Mardirossian, F. & Mezzetti, M. 1978, A&AS, 33, 91
Degirmenci, Ö. L., Sezer, C., Demircan, O., Erdem, A., Özdemir, S., Ak, H. & Albayrak, B. 1999, A&AS, 134, 327
Eggleton, P. P. 2008, IAUS, 246, 228
Eggleton, P. P. 2010, NewAR, 54, 45
Eldridge, J. J. 2009, MNRAS, 400, L20
Garmany, C. D. & Stencel, R. E. 1992, A&AS, 94, 211
Harries, T. J., Hilditch, R. W. & Hill, G. 1997, MNRAS, 285, 277
Høg, E., Fabricius, C., Makarov, V. V., et al. 2000, A&A, 355, L27
Hübscher, J., Agerer, F., & Wunder, E. 1991, BAVSM, 59, 1

Table 6: Observed and model parameters of the components.

	Star	M (M_{\odot})	log R	log T	log L	P (days)	Age (yr)
Observed	A	20.8	0.9269	4.5367	4.954	1.8855	
	B	27.9	0.9868	4.5563	5.152		
Model No 28	A	28.0	0.8687	4.5783	5.0039	1.6960	8.6×10^3
	B	23.5	0.8252	4.5532	4.8163		
Model No 201	A	20.83	0.9224	4.5401	4.9581	1.8860	3.85×10^6
	B	27.65	0.9741	4.5606	5.1440		

- Hübscher, J., Agerer, F., & Wunder, E. 1992, BAVSM, 60, 1
- Hübscher, J., Agerer, F., & Wunder, E. 1993, BAVSM, 62, 1
- Hübscher, J., Agerer, F., & Wunder, E. 1994, BAVSM, 68, 1
- Hübscher, J. 2011, IBVS, 5984, 1
- Kalomeni, B., Yakut, K., Keskin, V., Değirmenci, Ö. L., Ulaş, B. & Köse, O. 2007, AJ, 134, 642
- Koch, R. H., Siah, M. J. & Fanelli, M. N. 1979, PASP, 91, 474
- Landolt, A. U. 1964, ApJ, 140, 1494
- Landolt, A. U. 1975, PASP, 87, 409
- Lanz, T. & Hubeny, I., 2003, ApJS, 146, 417
- Massey, P., Johnson, K. E. & Degioia-Eastwood, K. 1995, ApJ, 454, 151
- Mayer, P. 1980, BAICz, 31, 292
- Mayer, P., Wolf, M., Muminovic, M. & Stupar, M. 1986, IBVS, 2942, 1
- Mayer, P., Hadrava, P., Harmanec, P. & Chochol, D. 1991, BAICz, 42, 230
- Mayer, P., Niarchos, P. G., Lorenz, R., Wolf, M. & Christie, G. 1998, A&AS, 130, 311
- Mayer, P., Lorenz, R. & Drechsel, H. 2002, A&A, 388, 268
- Morgenroth, O. 1935, AN, 255, 425
- Nagai, K. 2004, Var.Star Bull.Japan, 42, 1
- Paschke, A. 2010, OEJV, 130, 1
- Pearce, J. A. 1952, PASP, 64, 219
- Peter, H. 1992, BBSAG Bull., 102
- Peter, H. 1994, BBSAG Bull., 107
- Petrov, A.A. 1946, Perem. Zvezdy, 6, 72
- Popper, D. M. 1978, ApJ, 220, L11
- Popper, D. M. 1980, ARA&A, 18, 115
- Popper, D. M., & Hill G. 1991, AJ, 101, 600
- Prša, A., & Zwitter, T. 2005, ApJ, 628, 426
- Qian, S.-B., Yuan, J.-Z., Liu, L., He, J.-J. & Fernández Lajús, E., & Kreiner, J. Z. 2007, MNRAS, 380, 1599
- Rucinski, S. M. 1969, Acta Astron. 19, 245
- Uyaniker, B., Fürst, E., Reich, W., Aschenbach, B., & Wielebinski, R. 2001, A&A, 371, 675
- van Hamme, W. 1993, AJ, 106, 2096
- von Zeipel, H. 1924, MNRAS, 84, 665
- Wilson, R.E., & Devinney, E.J. 1971, ApJ, 166, 605
- Wilson, R.E. 1979, ApJ, 234, 1054
- Wilson, R.E. 1990, ApJ, 356, 613
- Yakut, K., & Eggleton, P. P. 2005, ApJ, 629, 1055
- Yakut, K., et al., 2013, in preparation
- Zasche, P., Uhlar, R., Kucakova, H., & Svoboda, P. 2011, IBVS, 6007, 1

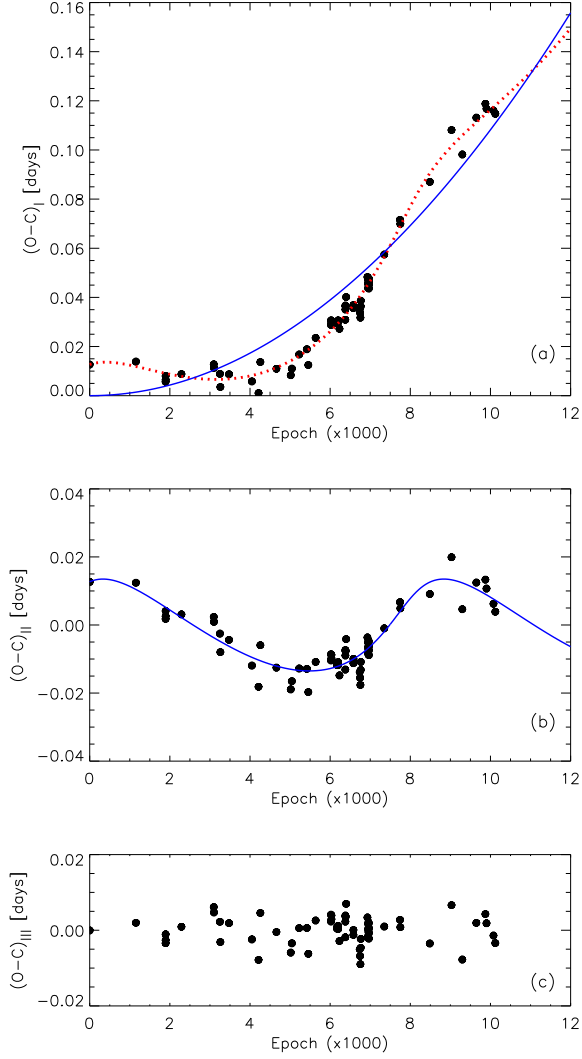


Fig. 2.— (a) Residuals for the times of minimum light of V382 Cyg. The solid line is obtained with the quadratic terms and the dotted line is obtained with parabolic+sinus terms in ephemeris Eq. 1. (b) The difference between the observations and the quadratic ephemeris and (c) final residuals.

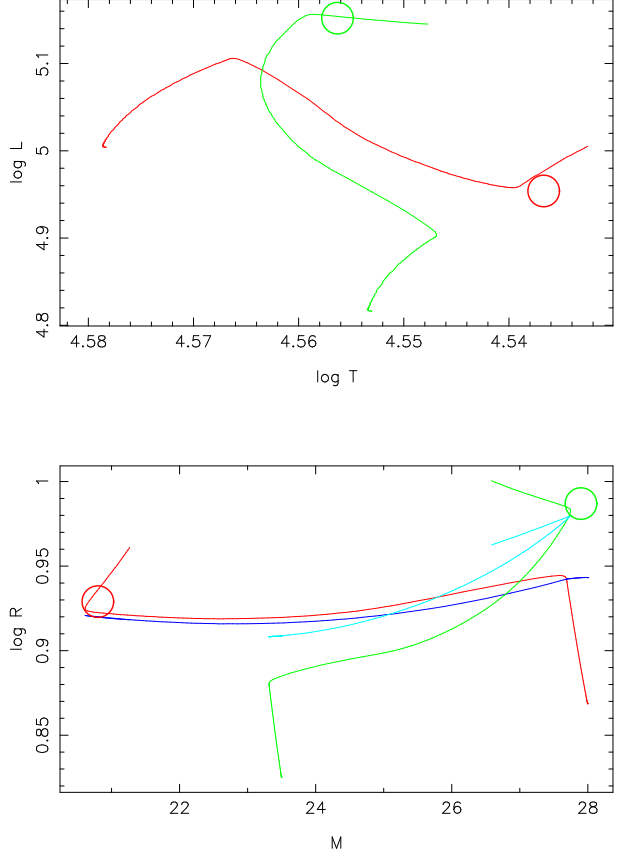


Fig. 3.— Non-conservative evolution of V382 Cyg in the $H - R$ diagram (top panel) and $\log R$ vs. M plane (bottom panel). More massive and less massive star are shown in red and green; their respective Roche-lobe radii are dark blue and light blue. Initial parameters are $28.0 M_{\odot}$, $23.5 M_{\odot}$ and 1.72 days with assumed Solar composition. The original primary is the secondary currently.